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CONCRETE PAVEMENT SLABS REINFORCED WITH STEEL FIBRES FROM DISCARDED VEHICLE TYRES

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Abstract

The increasing cost of steel reinforcing bars for concrete pavement slab construction in Ghana has rendered these slabs, made for walkways, car park lots and ground floor of buildings, to be constructed without reinforcement. Consequently, these pavements usually do not perform their design purposes satisfactorily as they easily fail when subjected to bending or impact loads. The quest for alternative and economic sources of steel for reinforcement to reduce the cost of pavement construction in Ghana has been on the increase in recent times. The objective of the study was to investigate the impact of steel fibres obtained from discarded vehicle tyres on the flexural strength of concrete pavement slabs. Four concrete cubes of dimensions 50×50×50 mm and four slabs of dimensions 50×50×160 mm were cast using 1:2:4 mix ratio. Two of the slabs were reinforced with steel wires obtained from the rim of discarded vehicle tyres as fibres, whilst the other two were made of plain concrete. The average flexural strength of the fibre-reinforced concrete slabs was $2.46N/mm^2$*, which was 146% higher than the plain concrete slabs that recorded average strength of* $1.00N/mm^2$*. It was concluded that steel fibres obtained from the rim of discarded vehicle tyres significantly improve the flexural strength of concrete pavement slabs and that they should be employed in walkways an vehicle parking lot pavement constructions in Ghana.*

Keywords: Discarded vehicle tyres, fibre-reinforced concrete, concrete pavement, flexural strength, plain concrete.

Introduction

Concrete is a brittle material consisting of four main components namely; coarse aggregates – which form the body of the concrete, fine aggregates – which fill the pores in the coarse aggregates, cement – which is added to bind the materials together and water – which hydrates the cement to initially make the concrete workable and later hardens it. Concrete produced from these constituent materials is usually very strong in compression but has a very low tensile resistance. The tensile strength of concrete is only about one-tenth of its ultimate compressive strength (Adom-Asamoah, 2003).

In Ghana and many other developing countries, concrete slabs used in walkways or pedestrian pavements and road lay-bys construction are generally unreinforced and therefore constitute brittle elements. The use of such unreinforced concrete elements arises as a result of the high cost of steel bars for reinforcement and also lack of awareness of the suitability of locally available materials for reinforcement, such as steel fibres obtained from discarded vehicle tyres, to improve the flexural strength, tensile strength, ductility and resistance to impact, fracture and abrasion (Kankam, 2003). The addition of steel fibres to plain concrete is intended both to improve the material‘s ductility and that of the structure in which it is used. Investigations on various types of fibres for concrete pavement reinforcement have been made which include, glass, steel, asbestos, polypropylene and other natural fibres such as coconut husk, sisal, sugar cane bagasse, jute, palm stalk and palm kernel (Racines and Pama, 1979; Mansur and Aziz, 1982; Aziz et al, 1984; Kankam, 1994, 1997 and 2003).

Steel fibres are known to increase the flexural strength of concrete, when used as reinforcement, and have been used in ground pavement slabs for roads where both flexural and impact strengths are important (Persson and Skarendahl, 1980). A study of the impact resistance of both plain and reinforced concrete containing steel fibre mesh has revealed remarkable increase in energy absorption of the latter (Fibre Mesh Company, 1989). Also, concrete reinforced by uniformly mixing or scattering short length steel fibres is superior in the tensile strength, bending strength, cracking load, toughness, shock resistance and other properties to unreinforced concrete. Strength characteristics of the steel fibre reinforced concrete depend on properties of the steel fibre to be mixed. The technology of steel fibre-reinforced concrete thus, already exists. However, due to the

high cost of steel fibres and other reinforcing materials for concrete reinforcement, the construction of pavement slabs for many pavement projects in Ghana, and many other developing countries, is done without reinforcement. This usually leads to premature failure of pavement slabs due to impact loads and other service loads that cause bending stresses in the slabs.

Steel fibres for concrete slab reinforcement can be obtained from many sources including those cut from steel wires to the required length, slit cold rolled steel sheet with width corresponding to the length of the fibre chopped by a rotating cutting edge or a pressing mill and a disc rotated on molten steel that extracts molten steel. There is a cheaper source of steel fibre in Ghana that is yet to be harnessed. This can be obtained from worn-out vehicle tyres, which are usually discarded indiscriminately in the environment, that pose health hazards as they serve as water receptacles that eventually become breeding sites for mosquitoes, consequently spreading malaria to inhabitants in communities where they exist.

Vehicle tyres contain several rounds of steel wires used to reinforce the tyre rim around the two peripheries. These steel wires, especially in worn out tyres, if found to be suitable as fibre reinforcement for concrete pavements, will serve a dual purpose of producing stronger pavement slabs at lower costs and reducing the breeding sites of mosquitoes in the environment. The objective of the study was to investigate the impact of steel fibres obtained from discarded vehicle tyres on the performance of concrete pavement slabs, by comparing the flexural strength of concrete slabs reinforced with steel fibres, obtained from discarded vehicle tyres, with plain concrete slabs.

Fibre-reinforced concrete

Fibres are usually applied in concrete to control plastic shrinkage and drying shrinkage cracking. They also lower the permeability of concrete and thereby, reducing bleeding of water onto the concrete surface. Some types of fibres yield greater impact, abrasion and shatter resistance in concrete. Generally fibres do not significantly increase the flexural strength of concrete, and that it cannot replace moment resisting or structural steel reinforcement. Fibre-reinforcement is mainly used in concrete to improve the tensile resistance of concrete elements. Fibre-reinforced concrete is mostly used for ground floor slabs, small chamber covers and pavements, but can be considered

for a wide range of construction parts including beams, pillars, foundations etc. either alone or with hand-tied reinforcement.

Concrete reinforced with fibres is less expensive than hand-tied reinforcement, while still increasing the tensile strength many times. Usually steel, glass or plastic materials are used as fibres for fibre-reinforcement of concrete. Shape, dimension and length properties of the fibres are important in fibre-reinforced concrete. A thin and short fibre, such as short hair-shaped glass fibre, will only be effective the first hours after pouring the concrete, as it reduces creeping while the concrete is stiffening, but will not increase the concrete tensile strength after the concrete has hardened. However, a standard size steel or plastic fibre based on the European Concreting Specifications of 1 mm diameter and 45 mm length will impact positively on a concrete element by increasing the tensile strength. The amount of fibres added to a concrete mix is measured as a percentage of the total volume of the composite which is termed as volume fraction (V_f). The V_f typically ranges from 0.1 to 3 %. Aspect ratio (l/d) is calculated by dividing the fibre length (l) by its diameter (d).

Steel fibre-reinforced concrete

Steel is the strongest commonly available fibre, and comes in different lengths of 30 to 80 mm in Europe with end-hook shape. Steel fibres can only be used on surfaces that can tolerate or avoid corrosion and rust stains. In some cases, the surfaces of steel-fibre reinforced concrete are coated with other materials to prevent corrosion. Early research on steel fibre reinforcement in concrete was performed in the 1950s and 60s. The first commercial steel fibre-reinforced concrete pavement in the US was placed in 1971 at a truck station near Ashland, Ohio. This was followed by two bridge deck overlays in Pennsylvania in 1972 that are still in service. Following those successful installations, steel fibres were used on a number of concrete pavement projects in the 1970s and 80s, and have since been used primarily in industrial floors, heavy-used pavements, airfields, parking structures, and bridge decks. Steel fibres are generally 12.7 – 63.5 mm long, and 0.45 – 1.0 mm in diameter. Some steel fibres have hooked ends and are collected in bundles that break apart during mixing of concrete for integration in the concrete; whilst others may be crimped in shape and unattached. Figure 1 shows an example of hook-end steel fibres. The usual amount of

steel fibres used in concrete ranges from 0.25 % to 2 % by volume or 20 – 157 kg/m^3 (American Concrete Pavement Association, 2003).

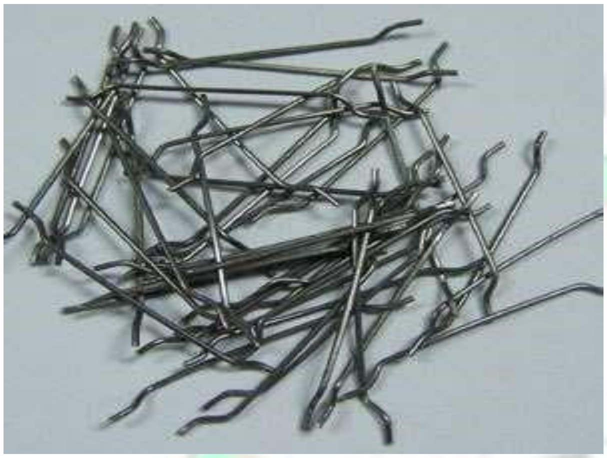

Figure 1: Hook-end steel fibres (Remix Steel Fibre Co., 2015)

The benefits of steel fibres in concrete include up to 150 % increase in the flexural strength, reduced potential for cracking during concrete shrinkage and increased fatigue strength. Studies have also shown that steel fibres can be used to increase the bending moment capacity and shear strength of reinforced concrete beams. A study by Shweta and Kavilkar (2014) indicates that the addition of steel fibres, especially those with a high aspect ratio, in concrete improves flexural toughness which is an indicator of ductility and crack resistance. Steel fibres have also been found to increase the splitting tensile strength of concrete.

Materials and methods

Discarded vehicle tyres were collected from the Sunyani ‗Magazine' area where vehicle repair garages operate and as a result, the practice of discarding worn-out vehicle tyres indiscriminately in the environment is on a high scale. A sharp-edged knife was used to peel off the rubber material from one side of the rim of the tyres after which a pair of pliers was used to pull the exposed steel wires out of the rim of the tyres one after the other until appreciable amount of the wires were obtained. The steel wires so removed were then cut into lengths of 20mm to ensure they could be

accommodated in the steel moulds used to cast the concrete elements. The diameter of the wires was measured with a set of callipers and was found to be 1mm on the average, giving an aspect ratio of 20 for the fibre samples prepared for the experiment. Figure 2 shows sample of the steel fibres removed from discarded vehicle tyres and cut for the experiment.

Figure 2: Steel fibres from the rim of discarded vehicle tyres

Concrete components

Ordinary Portland cement, satisfying the requirements of BS 12:1978, was used as a binding material for the concrete. 8mm granite aggregate were used as coarse aggregate and were mixed with sand and the cement to produce concrete. A mix ratio of 1:2:4 was used to batch the concrete components in respect of cement, sand and the coarse aggregate respectively. Clean tap water was used to mix the concrete with a water/cement ratio of 0.55, in accordance with the BS8110 (1997) for the production of concrete with characteristic compressive strength of 25 MPa at 28 days. Two steel moulds with dimensions 40 × 40 × 160 mm and 50 × 50 × 50 mm were used to cast concreted slabs and cubes respectively. Four concrete slabs and cubes were cast for testing. The slab samples included two reinforced with steel fibres obtained from discarded vehicle tyres and two others unreinforced. The four (4) cubes were of plain concrete which were subjected to compressive strength testing at 7 and 28 days. A steel fibre/cement ratio of 0.5 by weight was used for the reinforced concrete slabs.

Concrete was prepared by weighing each component material appropriately to the required weight into a metallic pan. The weights of the various components used are as shown in Table 1.

The components were then mixed thoroughly before steel fibres were spread in the mixture and further mixing was done to thoroughly integrate the steel fibres in the concrete matrix. The required amount of water was added and mixed finally to achieve a workable concrete. The concrete was then placed in the steel moulds and vibrated to eliminate trapped air bubbles (Figure 3). The specimens were removed after twenty-four hours and immersed in water and left until seven and twenty-eight days when they were removed for testing.

Table 1: Weight of component materials

Type of material	Mass of component material (Kg) (Cement : Sand : Coarse aggregate (1:2:4))			Total material (Kg)
	Reinforced slabs	Unreinforced	Cubes slabs	
Cement	0.181	0.181	0.177	0.539
Sand	0.362	0.362	0.354	1.078
Coarse Aggregate	0.728	0.728	0.708	2.164
Water	0.100	0.100	0.097	0.297
Steel fibre	0.091	-	-	0.091

Figure 3: Concrete slab samples cast in steel moulds

At the end of the curing period, the samples were removed from water, cleaned and weighed. They were then subjected to testing using the Dual-Compressive and Flexural Strength Testing Machine

(Figure 4). The cube samples were tested in the compression chamber by applying a compressive load, whilst the slabs were tested in the flexural chamber by applying a centrallyplaced point load to the samples. In both operations, the failure strength of the concrete samples was displayed on a transducer of the testing machine which were read and recorded.

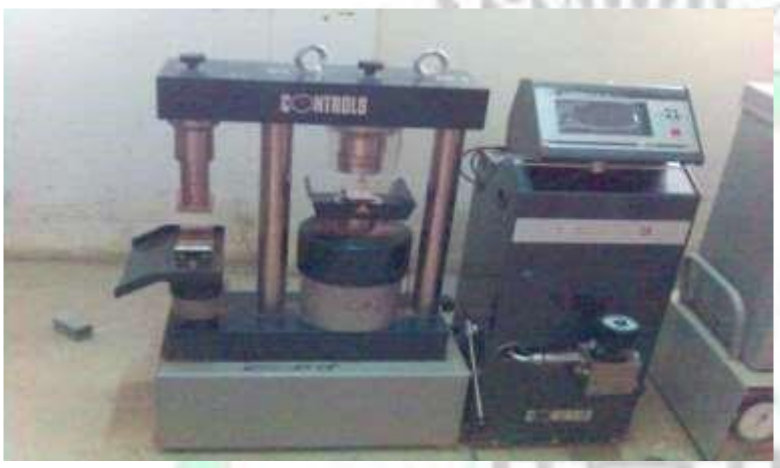

Figure 4: Dual flexural/compression testing machine

Results and discussions

The results of the compressive strength tests on the plain concrete cubes as well as the flexural strength of both the plain and fibre-reinforced concrete slabs were recorded and further discussed.

Cube strength

The average seven days characteristic compressive strength recorded for the concrete cubes was 19.96 MPa, whilst that of the 28 days was 20.70 MPa (Table 2). This shows that the concrete used was a medium grade concrete acceptable for plain concrete pavement slabs (BS 8110, 1997).

Table 2: Compressive strength of concrete cubes

Age of Test (Days)	7	28
Weight (Kg)	(A) 0.296	(A) 0.302
	(B) 0.296	(B) 0.299
Density (Kg/m^3)	(A) 2,368	(A) 2,416
	(B) 2,368	(B) 2,392
Average Density (Kg/m^3)	2,368	2,404
Compressive Strength (MPa)	(A) 19.94	(A) 21.16
	(B) 19.97	(B) 20.24
Average Compressive Strength (MPa)	19.96	20.70

Flexural strength of beams

The fibre reinforced concrete slabs recorded an average flexural strength of 2.46 MPa as compared to 1.00 MPa recorded for the un-reinforced concrete slabs (Table 3). This indicates that the average flexural strength of the fibre-reinforced concrete slabs was 146 % higher than that of the un-reinforced concrete or it is two and-half times higher. This higher flexural strength of the fibre-reinforced concrete slabs over the un-reinforced ones can be explained by the presence of the steel fibres in the concrete which improved significantly upon the tensile strength characteristics of the concrete, thereby improving the bending resistance of the beams made of the composite material relative to the ones made of plain concrete. Thus, the higher flexural strength indicates that, when concrete slabs are reinforced with steel fibre obtained from discarded vehicle tyres, a more robust composite material is obtained in terms of flexural resistance which will perform well in concrete pavement slabs such as walk-ways, ground-floor slabs, road lay-bys and car parks.

Table 3: Flexural strength of slabs

	Fibre-Reinforced	Un-reinforced
Flexural Strength (MPa)	(A) 2.56	(A) 1.05
	(B) 2.35	(B) 0.96
Average Flexural Strength (MPa)	2.46	1.00

Removal of steel fibres from discarded vehicle tyres

Burning of the tyres to remove the steel fibres was the easiest and most economical method for obtaining the steel fibres from the discarded vehicle tyres. However, it was found that this process was dangerous to the environment, as it would release chemicals that could affect the ozone layer thereby contributing to global warming. It was possible to extract the steel fibres from the rim of the discarded vehicle tyres by using a knife to cut and a pair of pliers to subsequently remove the wires. Albeit, the process was very cumbersome and quite dicey as a little error could result in a knife cut.

Conclusions

From the results obtained in the study, the following conclusions can be drawn:

The flexural strength of plain concrete slabs without fibre reinforcement increased from 1.00 MPa to 2.46 MPa when steel fibres obtained from discarded vehicle tyres were introduced. This represents 146 % improvement in the flexural strength of the concrete slabs reinforced with steel fibres obtained from discarded vehicle tyres compared to the ones made from plain concrete Concrete slabs reinforced with steel fibres obtained from discarded vehicle tyres constitute a more robust composite material in terms of flexural resistance. Thus, using steel fibres obtained from the rim of discarded vehicle tyres to reinforce concrete pavement slabs will improve their resistance to impact and other service loads in practice and will perform well in pavements such as walk-ways, ground-floor slabs, road lay-bys and car parks

Recommendations

- Discarded vehicle tyres should be collected from the environment and the steel wires found around their rims be removed to produce fibre-reinforced concrete pavement slabs in Ghana
- A mechanical device should be manufactured for easy removal of steel fibres from the rim of discarded vehicle tyres for fibre-reinforced concrete production to avoid the risk of knife cuts when removal is done manually with a knife and a set of pliers. In the meantime, removal of the wires manually could be done to generate employment

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